Training and Research in Oceanic and Atmospheric Processes in Tropical Cyclones (TROPIC)

Elizabeth R. Sanabia
United States Naval Academy
Oceanography Department
572C Holloway Rd.
Annapolis, MD 21402
phone: (410) 293-6556 fax: (410) 293-2137 email: sanabia@usna.edu

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LONG-TERM GOALS

The overarching goal of this research is to improve tropical cyclone (TC) forecast accuracy.

OBJECTIVES

Three principle objectives are designed to achieve the long-term goal:

1. Improve observational data quality,
2. Analyze variations between model and observed values of ocean heat content, and
3. Evaluate sensitivity of statistical-dynamical model TC intensity forecasts to observed values of ocean heat content.

APPROACH

The research program is divided into two phases: a field phase and a classroom phase. During the field phase, TROPIC personnel, including U.S. Naval Academy midshipmen (undergraduate students), flew with the USAF 53rd Weather Reconnaissance Squadron (WRS) to collect the data upon which this research is based. In addition to the standard suite of airborne reconnaissance sensors, more than 100 Airborne eXpendable BathyThermographs (AXBTs) were deployed to extend the data set to the ocean. The field phase was conducted with the 53rd WRS at Keesler Air Force Base during July-August 2011. The classroom phase began at the U.S. Naval Academy immediately following the field phase and will continue through the 2011-2012 academic year. During the classroom phase, the midshipmen will review and analyze data collected during the field phase to address the objectives of this research.

While TROPIC began as a collaborative effort with the Naval Research Laboratory (NRL), Monterey and the USAF 53rd WRS, an opportunity was leveraged to coordinate the field phase of this program with a parallel project undertaken by the Interdepartmental Hurricane Conference (IHC) working group. During the summer of 2011, the IHC working group began a 3-5 year forecast demonstration project in which AXBTs are launched from operational flights into Atlantic Basin TCs, the data are

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input into coupled air-sea models on a near-real-time basis, and the value added of these AXBTs to the coupled numerical model TC forecast output is evaluated. Operational and logistics support from the 53rd WRS for TROPIC research is substantially enhanced through this partnership, and in return, data from the AXBT drops are quality controlled, formatted, and uploaded to the Global Telecommunication System (GTS) by TROPIC personnel. The data are then available to scientists worldwide, including the Navy Coupled Ocean Atmosphere Mesoscale Prediction System – Tropical Cyclone (COAMPS-TC) and the National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC) conducting research on the Hurricane Weather Research and Forecast System (H-WRF) coupled mesoscale model to support the IHC Working Group.

Key personnel for the program and subject matter experts for each phase include:

a. Leads:

   CDR Elizabeth R. Sanabia PhD, USN, United States Naval Academy, Annapolis, MD (PI)

   Peter Black, PhD, Naval Research Laboratory, Monterey, CA

b. Field Phase:

   LtCol Jonathan Talbot, USAF, 53rd WRS, Keesler Air Force Base, Biloxi, MS

   Jeffrey Kerling, Naval Oceanographic Office, Stennis Space Center, Stennis, MS

c. Classroom Phase:

   Sue Chen, PhD, Naval Research Laboratory, Monterey, California

   Dong-Shan Ko, PhD, Naval Research Laboratory, Stennis Space Center, Stennis, MS

WORK COMPLETED

Work during the TROPIC field phase was focused in the areas of data collection, processing, dissemination, and assimilation (Fig. 1). Efforts were initially centered on successful AXBT deployment, then transitioned to timely and accurate quality control of the AXBT data in flight, then to optimizing the timing of transmissions from the aircraft to the Naval Oceanographic Office (NAVO) for optimal inclusion of the data into each model run. Work done to date during the TROPIC classroom phase has been focused on data organization, evaluation, and analysis. Efforts were initially centered on modifying code to streamline data output and organization, and while that continues, work has extended to evaluating data and initiating case studies. Details are provided below by phase/stage.

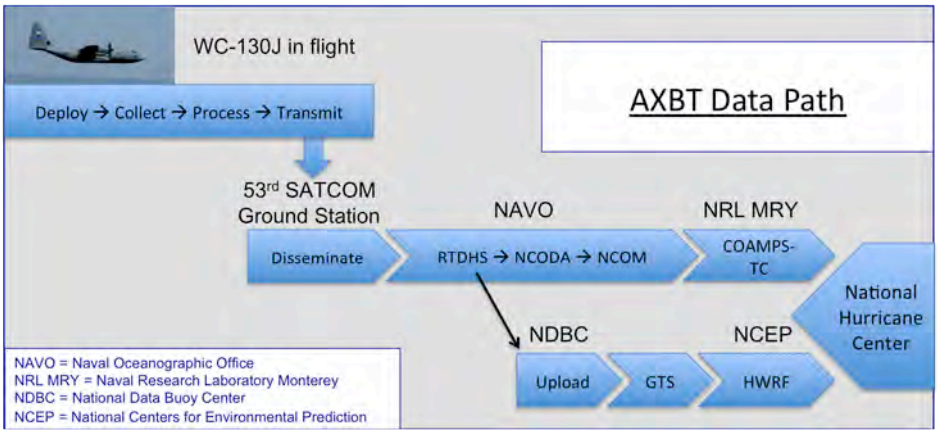

Fig. 1. Data path established during TROPIC field phase.

A. Field Phase / Collection:

Between 28 July – 28 August 2011, 90 AXBTs were released from USAF 53rd WRS WC-130J aircraft (Fig. 2) into 1 hurricane (Irene), 2 tropical storms (Don and Emily), and 1 tropical depression (pre-Harvey) in the Gulf of Mexico, central Caribbean, and western Atlantic as part of the TROPIC summer field phase. An additional 19 AXBTs were launched during one transit and two training flights. TROPIC personnel forward deployed with the 53rd WRS to St. Croix in support of TS Emily and pre-Harvey operations and to Savannah, Georgia in support of Hurricane Irene operations.

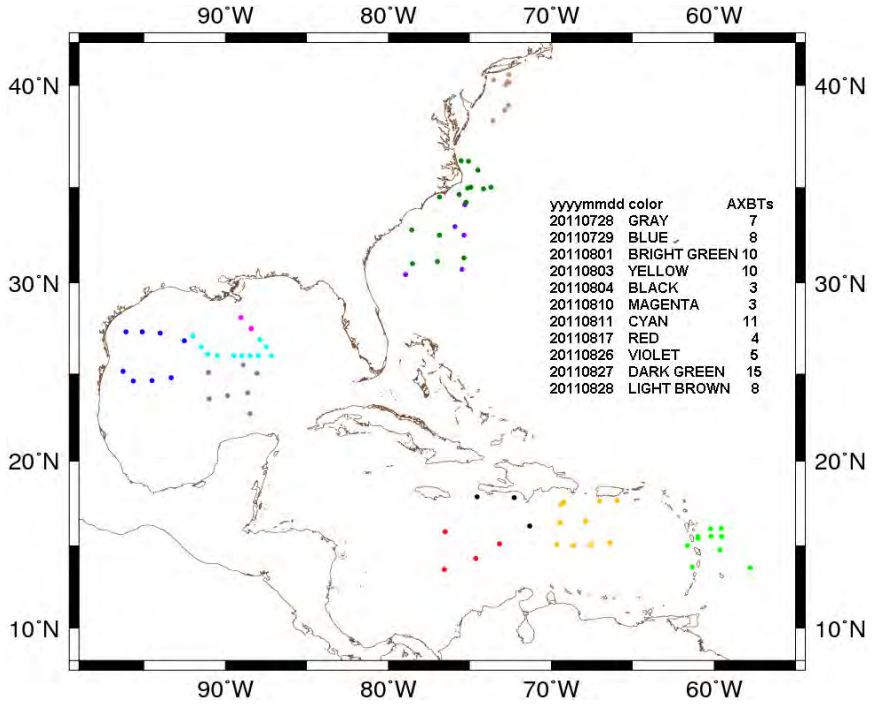

Fig. 2. Spatial distribution of the 85 AXBTs released during the 2011 TROPIC field phase that passed the NAVO Real-Time Data Handling System quality control check (courtesy Carl Szczechowski, NAVO).

B. Field Phase / Processing:

The field phase processing stage was the focal point for improving data quality (the first research objective). In previous research programs there was a disconnect between the audio and digital data files, particularly with regard to marking the surface in the digital data. Many of the issues revolved around consistency in drop and processing procedures, and for that reason, seven Standard Operating Procedures (SOPs) were written during the field phase to facilitate a systematic approach to AXBT field operations. These SOPs covered the following topics:

1. Equipment Setup
2. Mission Planning Brief
3. AXBT Flight Operations
4. AXBT Recording and Initial Processing
5. AXBT Post-Processing
6. Ground Operations
7. Deployment Preparation

The value of this standardization will be assessed during the classroom phase of the program.

C. Field Phase / Dissemination:

Of the 109 total AXBTs released from the WC-130Js, data from 85 were transmitted to NAVO and passed the Real-Time Data Handling System (RTDHS) quality control check (Fig. 2) (a 78.0% initial success rate, with final success defined as assimilation into the model). Grouped by intensity, the 69 AXBTs deployed into systems at or below TS intensity had an 81.2% initial success rate. The 40 AXBTs deployed into Hurricane Irene had a slightly lower initial success rate of 72.5%. The baseline for operational reliability of AXBTs is 90%, which is the Fleet average for AXBTs within their 5-year shelf life. The AXBTs used in TROPIC were provided by the Naval Research Laboratory, Monterey and were procured for research as a result of exceeding their operational shelf lives.

To extend the availability of these data to the scientific community, a data pathway was established between NAVO and the National Data Buoy Center (NDBC) (Fig. 1). Following the RTDHS quality control check at NAVO, NDBC pulled the data by ftp and then posted them to the Global Telecommunication System (GTS). Once on the GTS, the data were available to the scientific community worldwide.

D. Field Phase / Assimilation:

Within NAVO, after passing the RTDHS quality control check, the TROPIC AXBT data were assimilated by the Navy Coupled Ocean Data Assimilation (NCODA) system into the Navy Coastal Ocean Model (NCOM). The NCOM provides the global scale ocean background fields for the mesoscale ocean in the coupled COAMPS-TC. The NCOM and AXBT data were incorporated into coupled COAMPS-TC runs by Sue Chen and Jim Cummings at NRL Monterey.

The value of these AXBT observations is made qualitatively clear when examining the observation data (Fig. 3) assimilated into the 1200 UTC 03 August 2011 NCOM run. The AXBTs released into TS Emily southwest of Puerto Rico were the only sea surface temperature observations available beneath the clouds surrounding this tropical storm. Further, the sub-surface AXBT thermal profile data impacted the modeled ocean in the coupled COAMPS-TC, resulting in a change of over 2^{o}C at 200m depth. Deployment of these AXBTs into the ocean beneath TCs routinely fills the data void beneath these tropical systems. The impact of these data on the modeled ocean has been observed and is being systematically quantified. The impact of the AXBT data on the TC forecast requires further analysis.

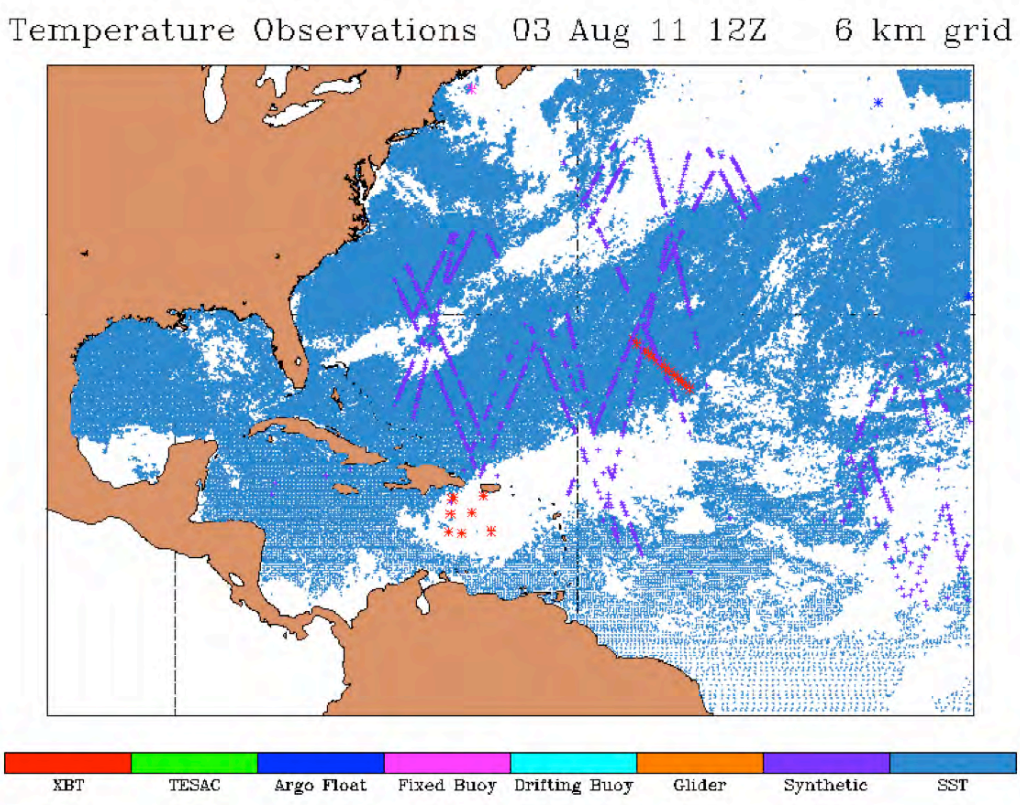

Fig 3. Sea surface temperature observations assimilated by NCODA in the 1200 UTC 03 August 2011 coupled COAMPS-TC model run (courtesy Sue Chen, NRL Monterey).

Two challenges during this period involved the timing of submissions to the Real-Time Data Handling System (RTDHS) at NAVO and the depths of AXBT observations. An inadvertent error resulted in a 24-h delay for all data received by the RTDHS between 2200-2359 UTC each day. This error has been corrected, and an investigation into the impact on inclusion/rejection of data in various model runs is in progress. A second challenge involved the depth of each AXBT profile. The NCODA system categoricaly rejects drops with data for depths less than 300m, and also those that have data at greater depths than in the model topography. Assessment of the impacts of these restrictions is underway and corrective and/or adaptive measures are forthcoming.

E. Classroom Phase / Organization:

1. The AXBT data processing programs are being modified to provide rapid profile visualization over a modeled ocean environment and to facilitate WC-130J route planning which will improve coordination of drop locations with the WC-130J crew prior to and during operational missions.

2. Data archiving procedures and file structures are being optimized to enhance usability.

F. Classroom Phase / Evaluation:

1. Data from the field phase is being evaluated for inclusion in analyses addressing each research objective.

2. Processes utilized during the field phase are also being modified to improve data quality, optimize in-flight operations, and streamline the data path.

G. Classroom Phase /Analysis:

1. Comparison of observed and modeled values of ocean heat content is underway to address the second research objective. Model imagery of ocean heat content was available at 12-h intervals during the field program (Fig 4). Digital profile data for the Intra-American Seas Nowcast Forecast System (IASNFS) have been provided by Dong-Shan Ko from NRL Stennis. Digital profile data for the coupled COAMPS-TC are being provided by Sue Chen and Jim Cummings from NRL Monterey.

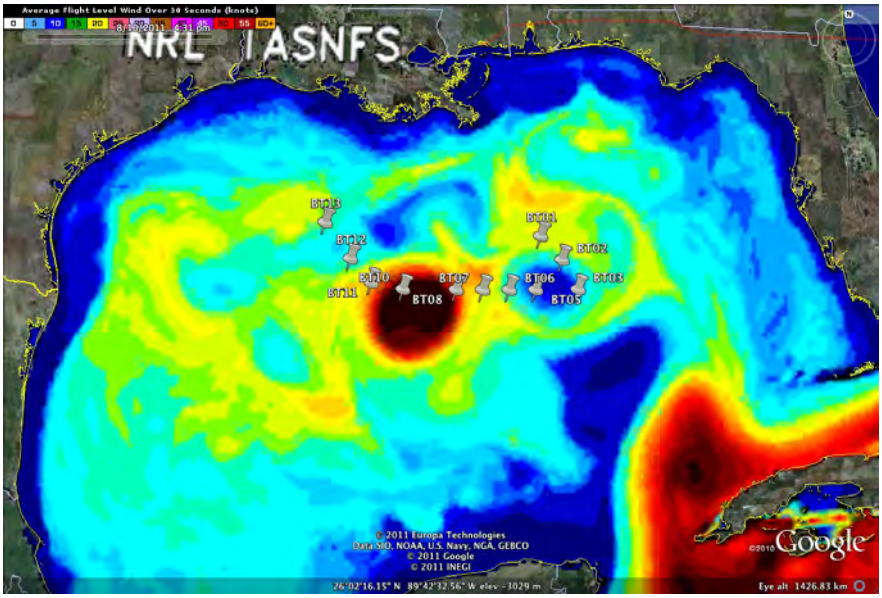

Fig 4. Locations of AXBT drops (white pushpins) detailed over the Intra American Seas Nowcast Forecast System (IASNFS) modeled Ocean Heat Content (warm colors indicate higher ocean heat content values and cool colors represent lower ocean heat content values).

The first analysis of modeled vs. observed ocean heat content is focused on the warm core eddy cut off from the Loop Current in the Gulf of Mexico, which was sampled during a training flight on 11 August 2011. Thirteen AXBTs were dropped in one zonal and two meridional cross sections that spanned the region of warm sea-surface temperatures and high ocean heat content (Fig. 4). Analysis of the differences in structure in the absence of TC forcing will be used to baseline further examination of differences each TC case. Differences in the modeled and observed values of ocean heat content will then be analyzed within the framework of a statistical-dynamical model to evaluate differences on forecast TC intensity (and fulfill research objective 3).

2. A second case study is focused on the evolution of the thermal structure (Fig. 5) in the western Atlantic near Cape Hatteras during the passage of Hurricane Irene. Two AXBTs were released within 10 nm in space and 17 hours in time as the hurricane transited northward along the eastern seaboard. Available AXBT and atmospheric data will be analyzed to characterize the causes and

effects of this heat loss in the upper ocean as a result of hurricane passage over the 17+ hours between the two drops.

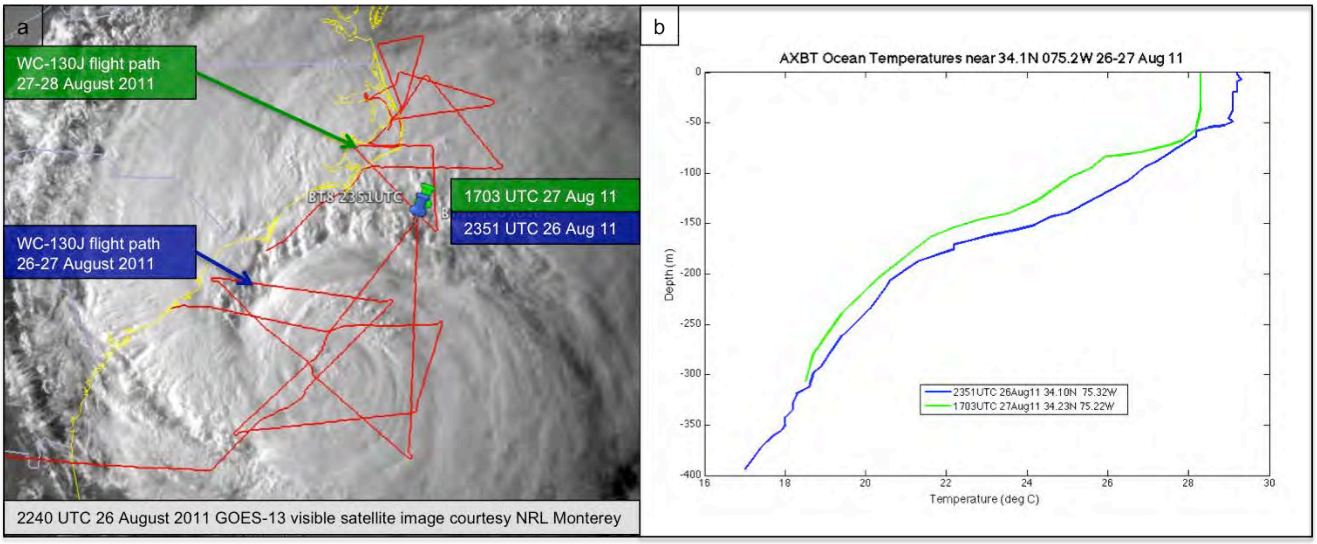

Fig. 5. (a) The AXBT drop locations from 2351 UTC 26 August 2011 (blue pushpin) and 1703 UTC 27 August 2011 (green pushpin) in relation to WC-130J reconnaissance flight tracks for Hurricane Irene (red lines) over GOES-13 visible satellite imagery from 2240 UTC 26 August 2011. (b) Ocean temperature profiles from the AXBT drops marked in (a) near 34.15°N, 075.25°W from 2351 UTC 26 August 2011 (in blue) and 1703 UTC 27 August 2011 (in green).

RESULTS

Several operational and research "firsts" occurred during the TROPIC field phase and are listed below:

1. First operational deployment of AXBTs from WC-130J Hurricane Hunter Aircraft in Atlantic TCs.
2. First near-real-time assimilation of AXBT data from Atlantic TCs into the coupled COAMPS-TC model.
3. Established the first data path from the aircraft to the GTS for use during operational hurricane reconnaissance missions.

Research results to date are listed below by objective:

1. Data quality has been improved by:
   - A. providing ocean data in the data sparse areas beneath TCs
   - B. standardizing AXBT drop, processing, and transmission procedures
   - C. collecting and analyzing assimilation statistics (in progress)
   - D. establishing a data pathway to make AXBT data available worldwide in near-real-time

2. Comparison of model and observed values of ocean heat content: in progress.
3. Evaluation of the sensitivity of statistical-dynamical model TC intensity forecasts to observed values of ocean heat content:
   A. Assimilation of AXBT data resulted in an adjustment of the ocean thermal structure in the coupled COAMPS-TC model of 2^{o}C at 200m depth.
   B. Consistency of this adjustment and the subsequent impact on TC forecast accuracy will be analyzed.

IMPACT/APPLICATIONS

1. The lessons learned from the TROPIC program will impact AXBT operations through the remainder of the 3-5 year IHC working group forecast demonstration project in several areas:
   A. development and refinement of AXBT systems and procedures, including deployment hardware, data processing software, quality control, and data dissemination.
   B. definition of the optimal spatial and temporal distribution of AXBT drops within and between reconnaissance flights.
   C. refinement of assimilation schemes and scheduling for coupled TC forecast model runs.

2. Research may indicate that AXBT data improve TC forecast accuracy. If this is the case, the potential impacts on science and systems include:
   A. The IHC working group may recommend including AXBT operations become standard during airborne hurricane reconnaissance missions onboard the USAF 53rd WRS WC-130J.
   B. The coupled models including these data may become part of the NHC suite of forecast models.

RELATED PROJECTS

1. The Naval Research Laboratory, Monterey receives Hurricane Forecast Improvement Project (HFIP) funding from NOAA to support the near-real-time assimilation of AXBT data into coupled mesoscale models (COAMPS-TC) to enhance TC forecast accuracy.

2. The Naval Research Laboratory, Monterey also receives National Oceanographic Partnership Program funding from the Office of Naval Research and NOAA to improve the performance of coupled mesoscale models (including the coupled COAMPS-TC).